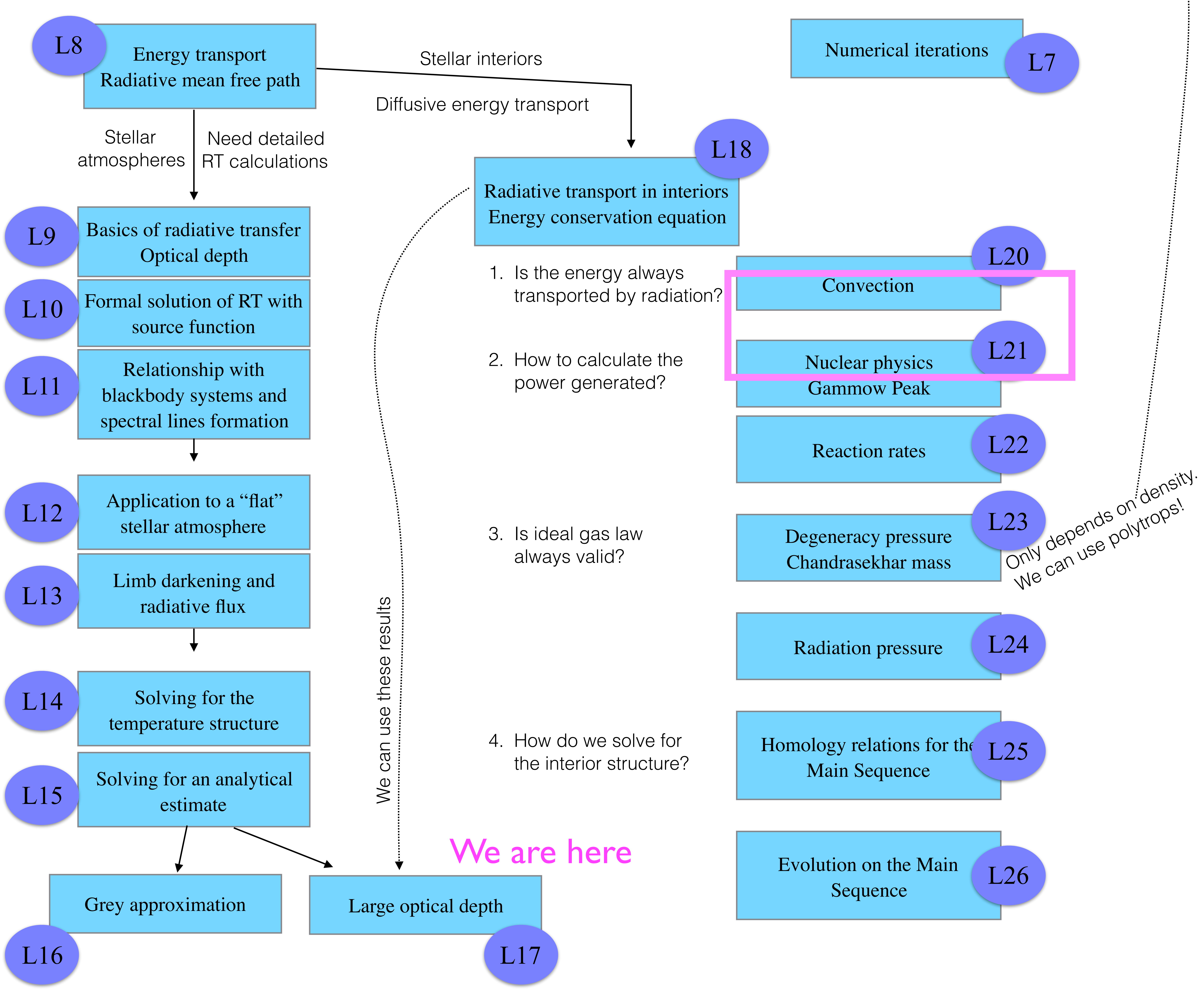
Week 11 Tuesday
L-19
End of convection
Nuclear reactions



L8
Energy transport
Radiative mean free path
Stellar interiors
Diffusive energy transport
Stellar atmospheres
Need detailed RT calculations
L7
Numerical iterations
L18
Radiative transport in interiors
Energy conservation equation
L9
Basics of radiative transfer
Optical depth
L10
Formal solution of RT with source function
L11
Relationship with blackbody systems and spectral lines formation
L12
Application to a "flat" stellar atmosphere
L13
Limb darkening and radiative flux
L14
Solving for the temperature structure
L15
Solving for an analytical estimate
L16
Grey approximation
L17
Large optical depth
We can use these results
We are here
1. Is the energy always transported by radiation?
2. How to calculate the power generated?
3. Is ideal gas law always valid?
4. How do we solve for the interior structure?
L20
Convection
L21
Nuclear physics
Gammow Peak
L22
Reaction rates
L23
Degeneracy pressure
Chandrasekhar mass
Only depends on density.
We can use polytrops!
L24
Radiation pressure
L25
Homology relations for the Main Sequence
L26
Evolution on the Main Sequence

Unstable if:

Let's ignore the gradient of μ for a moment, to simplify things

$$\nabla_{\rm med} > \nabla_{\rm ad}$$

$$\nabla_{\rm med} = \frac{3\kappa_R P L_r}{64\pi\sigma G M_r T^4}$$

$$\nabla_{\rm ad} = \frac{\gamma - 1}{\gamma}$$

$\gamma = \frac{5}{3}$ for a mono-atomic ideal gas

Q: When is $\nabla_{\rm med}$ ($\nabla_{\rm rad}$) large?

Notebook: 2 example stars (Sun, 10 times the mass of the Sun)

1. Where is κ_R large (hint, it will matter)
2. Where are these stars convective?

mesa.sourceforge.net

MESA
Modules for Experiments in Stellar Astrophysics

- MESA home
- code capabilities
- prereqs & installation
- getting started
- using pgstar
- using MESA output
- beyond inlists (extending MESA)
- troubleshooting
- FAQ
- star_job defaults
- controls defaults
- pgstar defaults
- binary_controls defaults
- news archive
- documentation archive

MESA

You may also want to visit ***the MESA marketplace****, where users share the inlists from their published results, tools & utilities, and teaching materials.*

Why a new 1D stellar evolution code?

The MESA Manifesto discusses the motivation for the MESA project, outlines a MESA code of conduct, and describes the establishment of a MESA Council. Before using MESA, you should read the **manifesto document**. Here's a brief extract of some of the key points

Stellar evolution calculations remain a basic tool of broad impact for astrophysics. New observations constantly test the models, even in 1D. The continued demand requires the construction of a general, modern stellar evolution code that combines the following advantages:

- **Openness**: anyone can download sources from the website.
- **Modularity**: independent modules for physics and for numerical algorithms; the parts can be used stand-alone.
- **Wide Applicability**: capable of calculating the evolution of stars in a wide range of environments.
- **Modern Techniques**: advanced AMR, fully coupled solution for composition and abundances, mass loss and gain, etc.
- **Comprehensive Microphysics**: up-to-date, wide-ranging, flexible, and independently useable microphysics modules.

Latest News

- 08 Apr 2017
  » **MESA Marketplace**
- 17 Feb 2017
  » **Release 9575**
- 25 Jan 2017
  » **Diffusion Updates**
- 08 Jan 2017
  » **Summer School 2017**
- 10 Aug 2016
  » **Documentation Archive**
- 19 Jun 2016
  » **Release 8845**
- 03 Feb 2016
  » **Release 8118**
- 29 Jan 2016
  » **New MESA SDK Version**
- 10 Jan 2016
  » **Summer School 2016**
- 27 Sep 2015
  » **Instrument Paper 3**

mesastar.org

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Welcome to the MESA Marketplace.

This month's featured shareware:

Josiah Schwab's mesa-major-mode repository:

An Emacs major mode and some related minor-modes intended for use when editing the work directory files (inlists and run_star_extras.f) used by the MESA stellar evolution code.

Recent Papers using MESA

The contraction/expansion history of Charon with implications for its planetary-scale tectonic belt

Malamud, Uri, Perets, Hagai B., and Schubert, Gerald

The statistical challenge of constraining the low-mass IMF in Local Group dwarf galaxies

El-Badry, Kareem, Weisz, Daniel R., and Quataert, Eliot

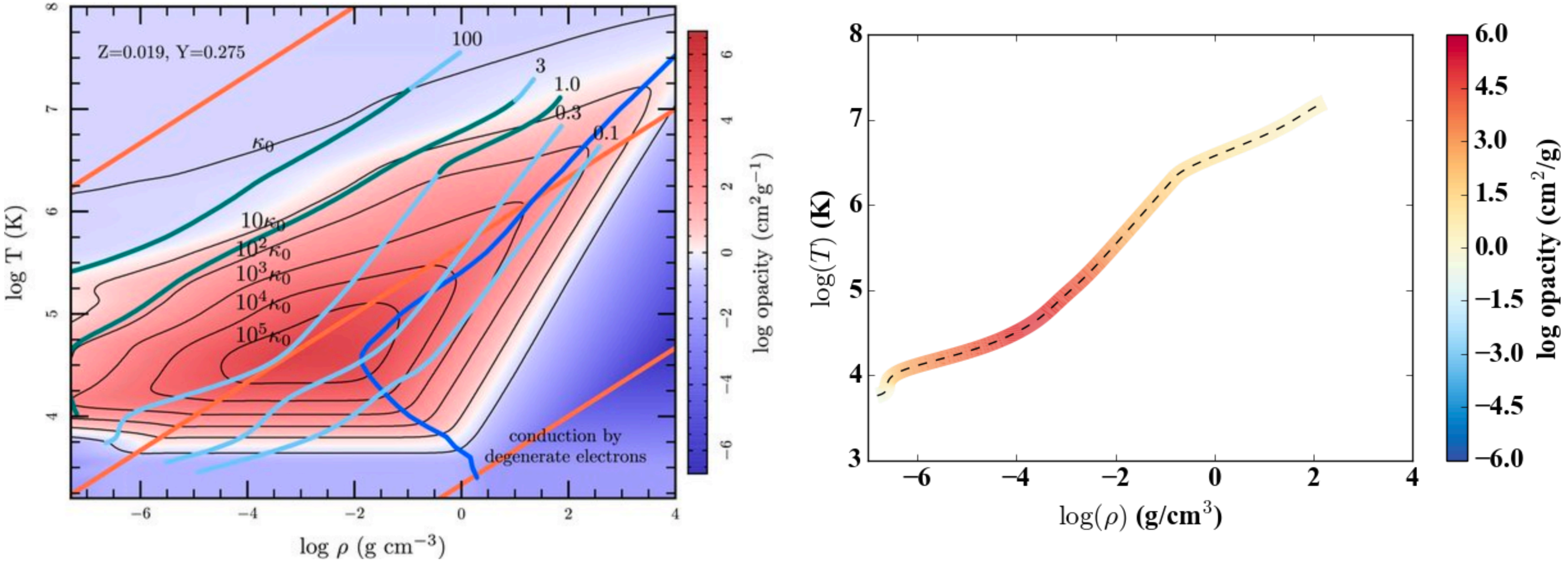
Period—luminosity relations of fast-rotating B-type stars in the young open cluster NGC 3766

Saio, H., Ekström, S., Mowlavi, N. et al.

On the nature of the candidate T-Tauri star V501 Aurigae★

Vaňko, M., Torres, G., Hambálek, L. et al.

Paxton et al. 2011, Fig. 3



Kip (first edition) fig 22.7
(hint for notebook interpretation: read the textbook!)

$$\frac{dM_r(r)}{dr} = 4\pi r^2 \rho(r)$$

$$\frac{dP(r)}{dr} = -\rho(r)\frac{GM_r(r)}{r^2}$$

$$\frac{dT(r)}{dr} = -\frac{3\kappa_R(r)\rho(r)}{64\pi\sigma}\frac{L_r(r)}{r^2 T(r)^3}$$

$$\frac{dL_r(r)}{dr} = 4\pi r^2 \rho(r)\epsilon(r)$$

$$M_r(r) \quad P(r) \quad L_r(r) \quad T(r)$$

$$\rho(r) \quad \mu(r) \quad \epsilon_{\text{nuc}}(r) \quad \kappa_R(r)$$

$$P(r) = \frac{\rho(r)}{\mu(r)}kT(r)$$

$$\mu(r) = f(\text{comp}, T(r), P(r))$$

$$\kappa_R(r) = f(\text{comp}, T(r), P(r))$$

$$\epsilon_{\text{nuc}}(r) = f(\text{comp}, T(r), P(r))$$

Other energy transport?

Ideal gas always valid?

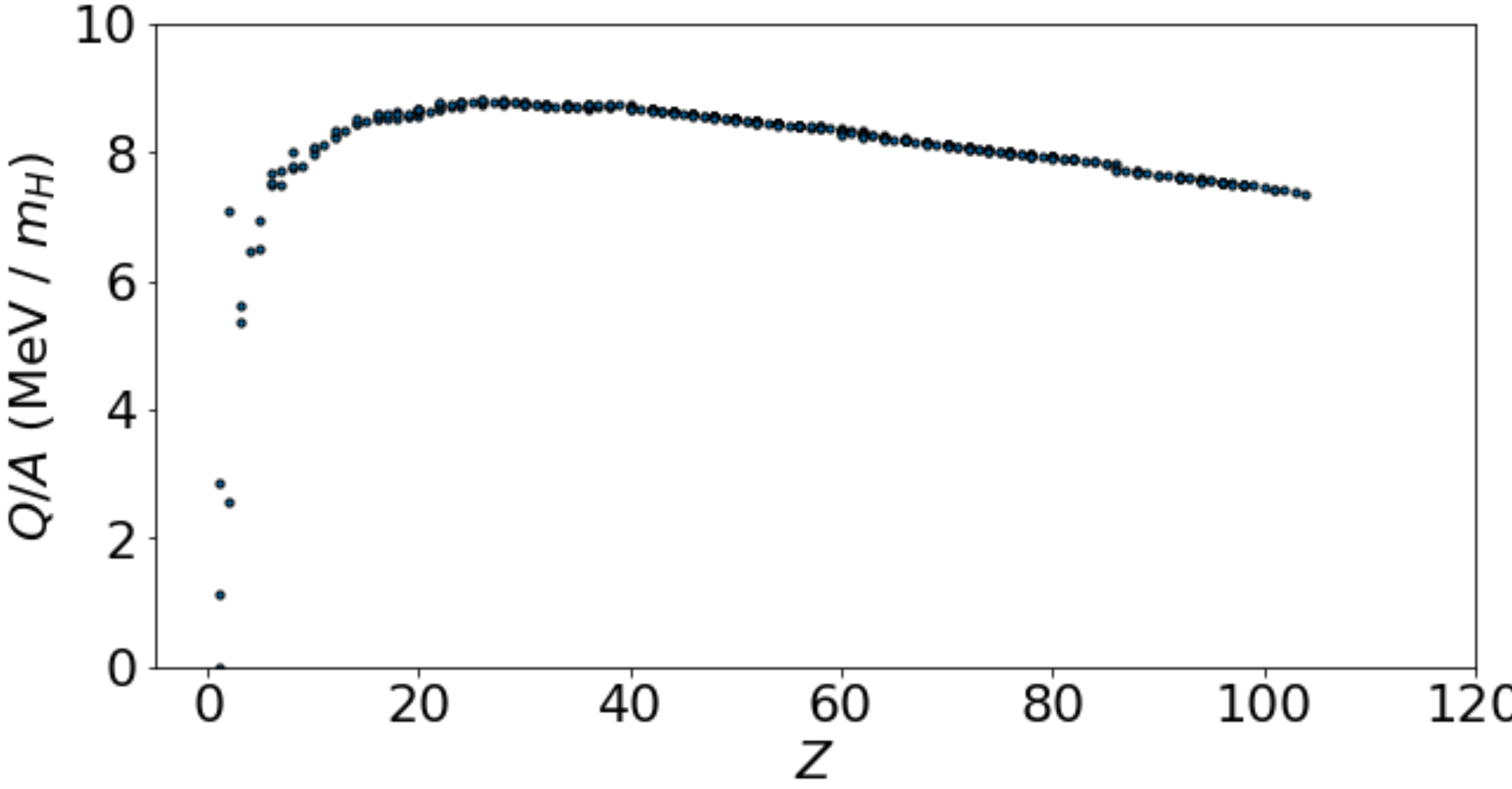
Nuclear mechanism?

How to solve?

What changes with time?

Nuclear binding energy: difference between the mass of a bound nucleus and the mass of its constituents.

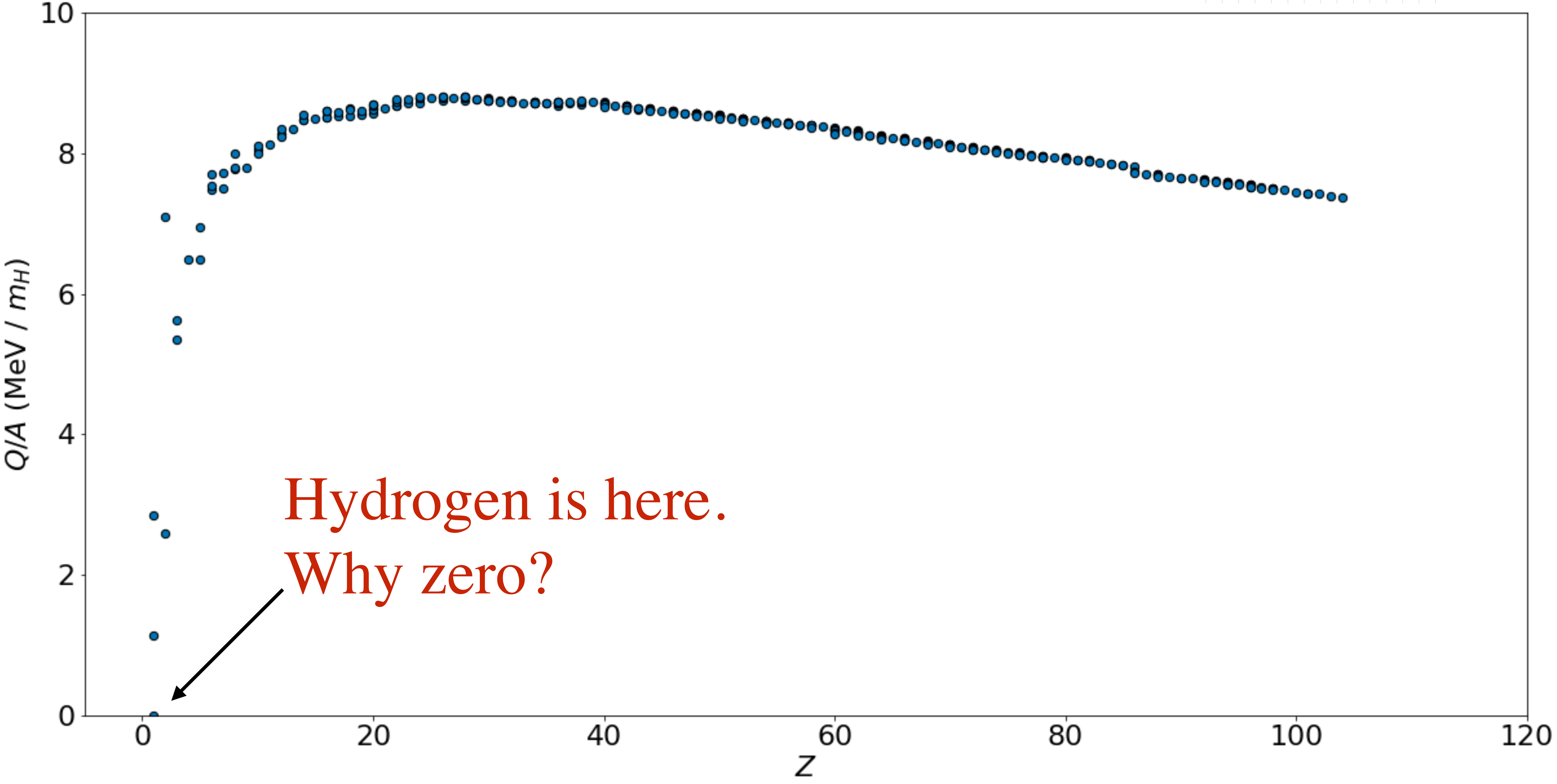
$$Q(Z,N) = \left[\; Zm_p + Zm_e + Nm_n \quad - \quad m(A,Z) \; \right] c^2$$



$$1 \text{ eV} = 1.602 \times 10^{-12} \text{ erg} = 1.602 \times 10^{-19} \text{ j}$$

$$1 \text{ MeV} = 1.602 \times 10^{-6} \text{ erg} = 1.602 \times 10^{-13} \text{ j}$$

$$Q(Z,N) = \left[\; Zm_p + Zm_e + Nm_n \;-\; m(A,Z) \;\right] c^2$$



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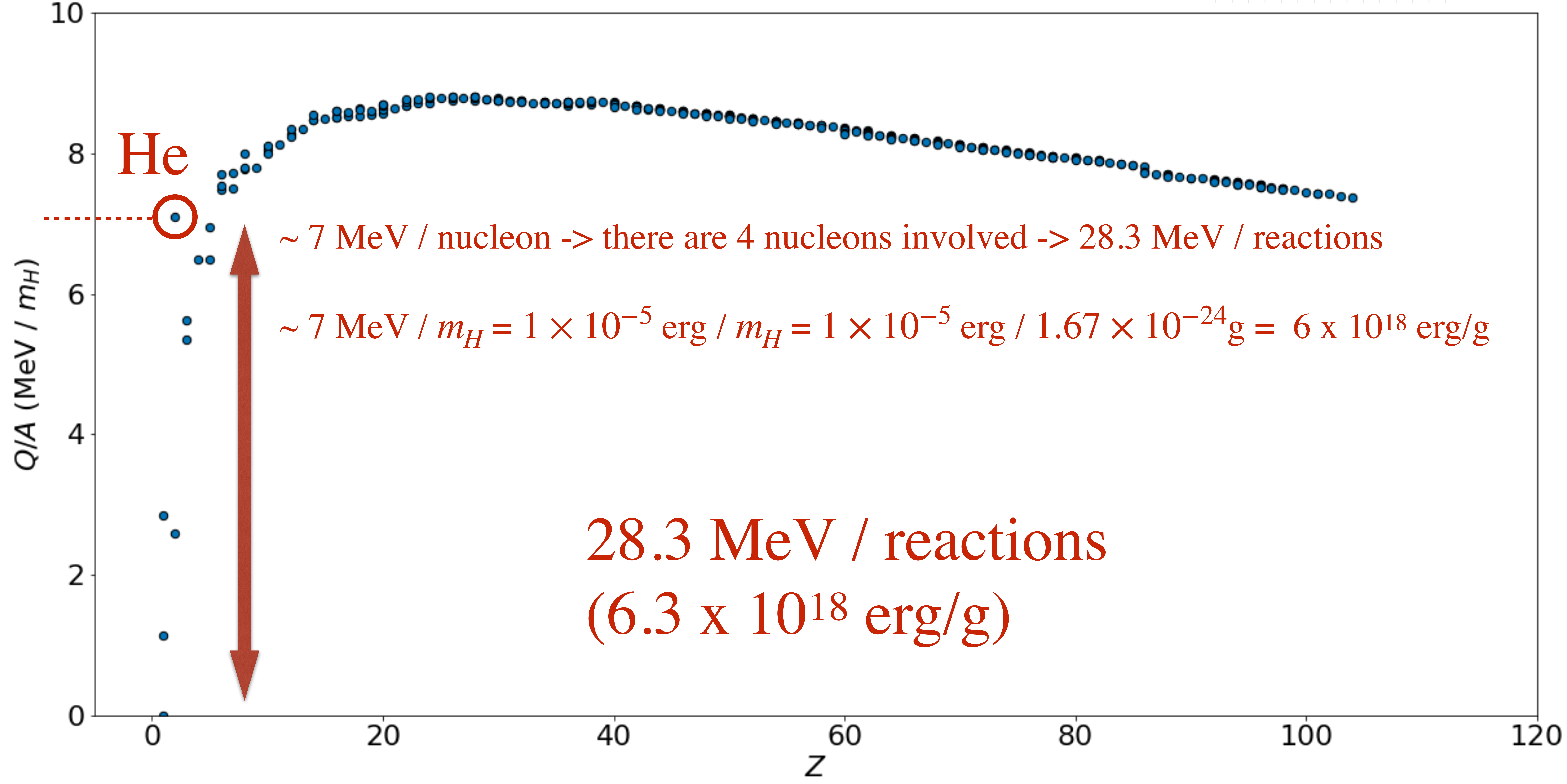

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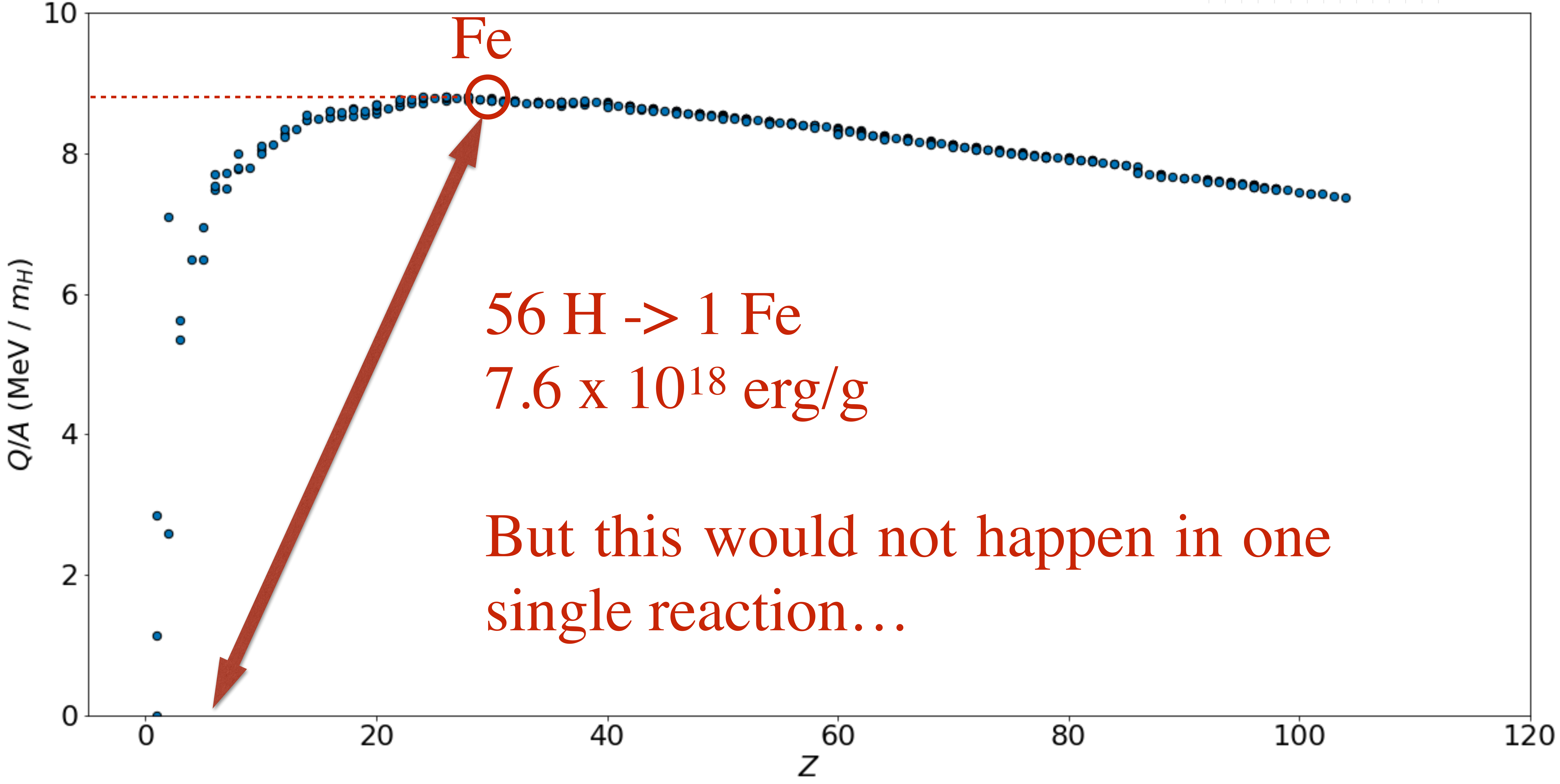
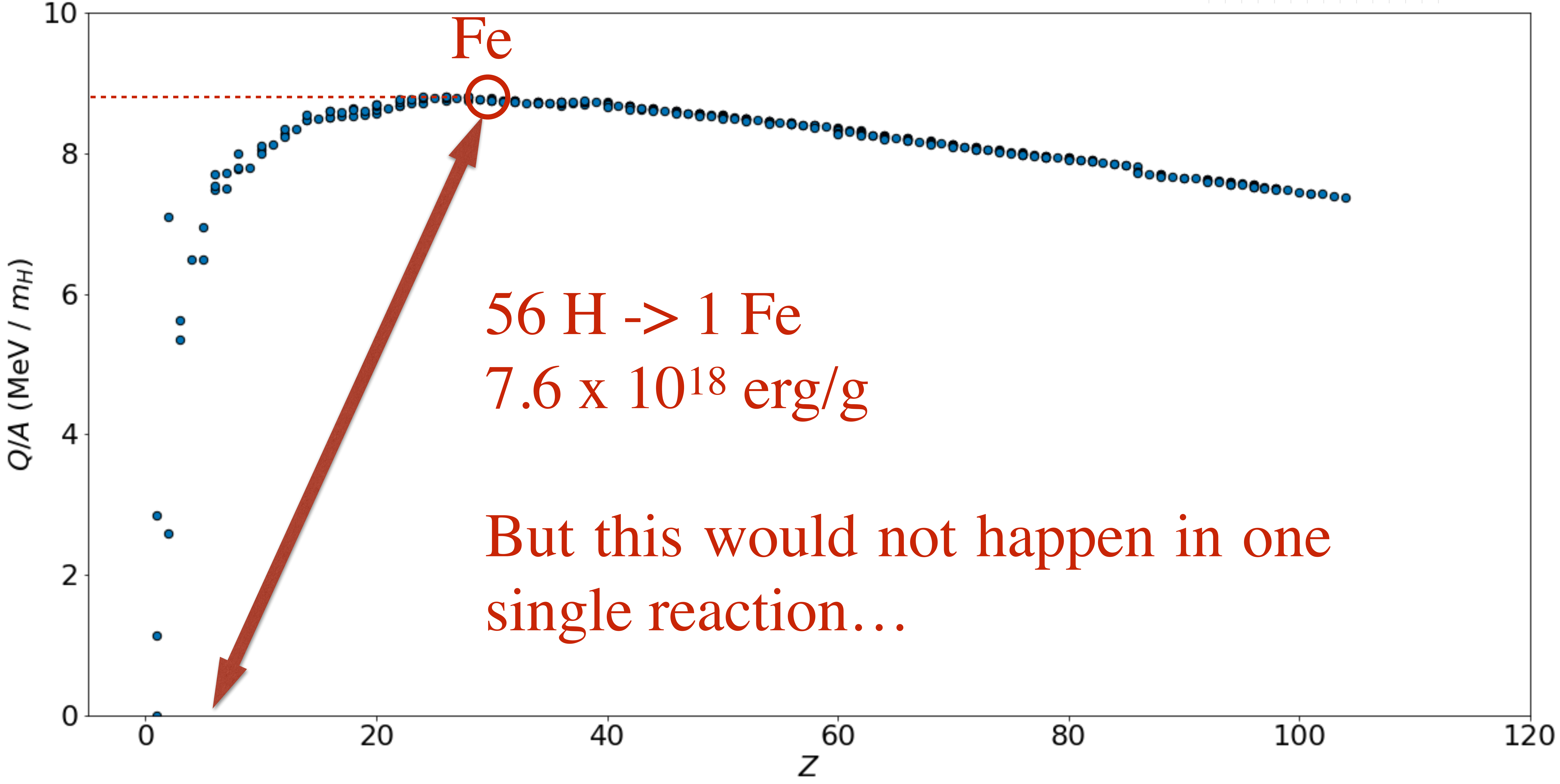


56 H -> 1 Fe

7.6 x 10^{18} erg/g

But this would not happen in one single reaction…

$$Q(Z,N) = \left[\; Zm_p + Zm_e + Nm_n \quad - \quad m(A,Z) \;\right] c^2$$



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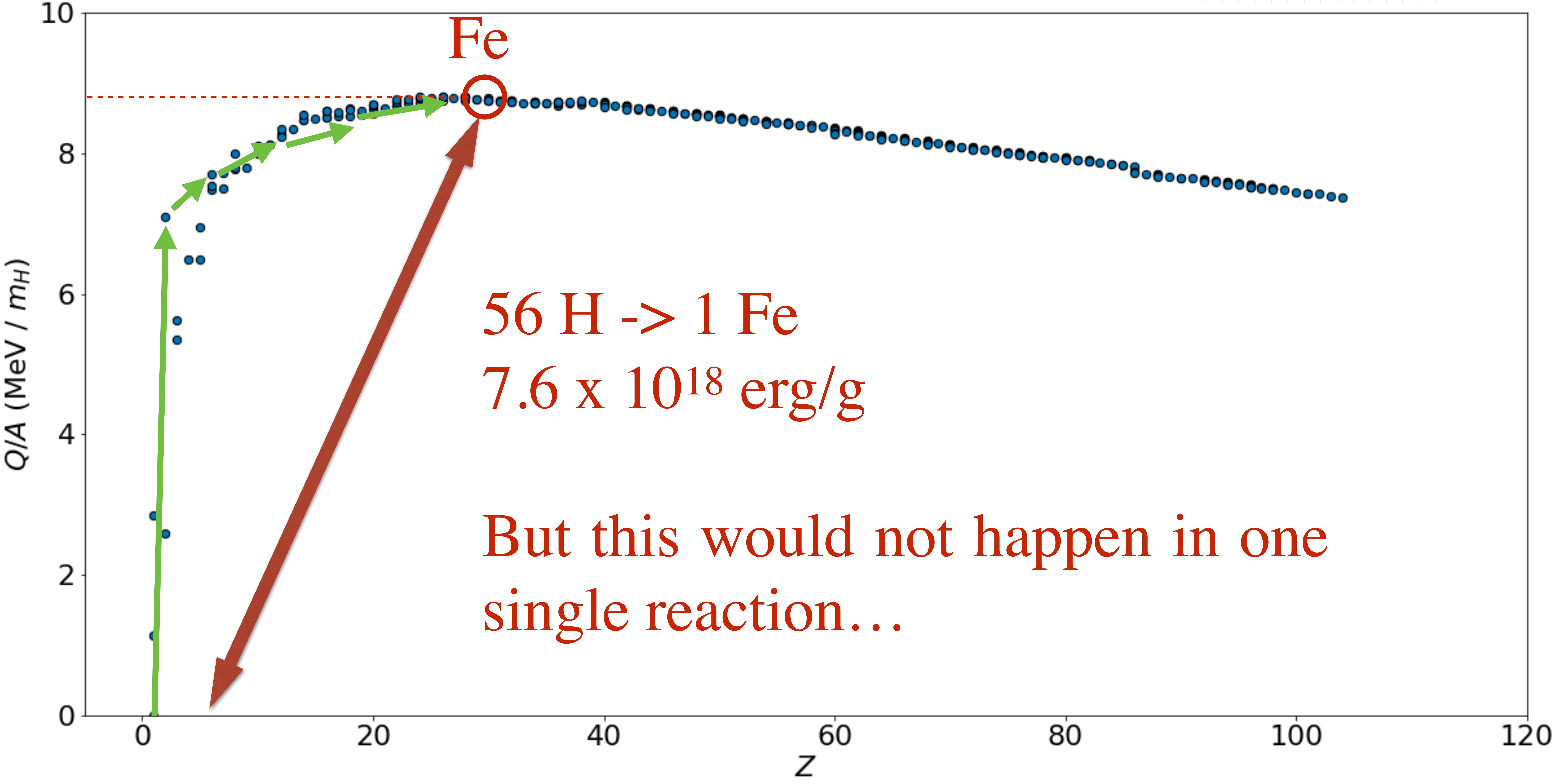

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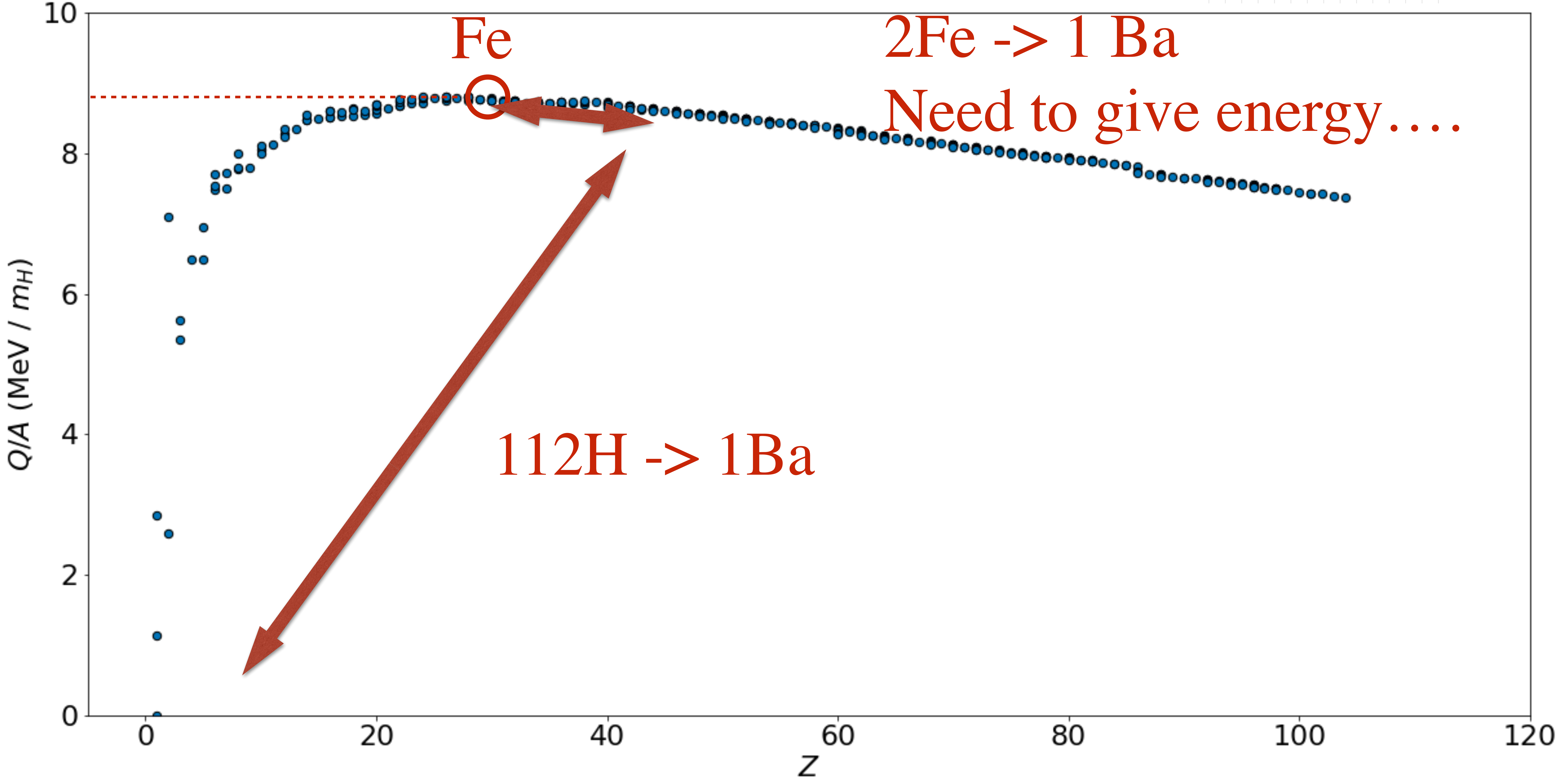
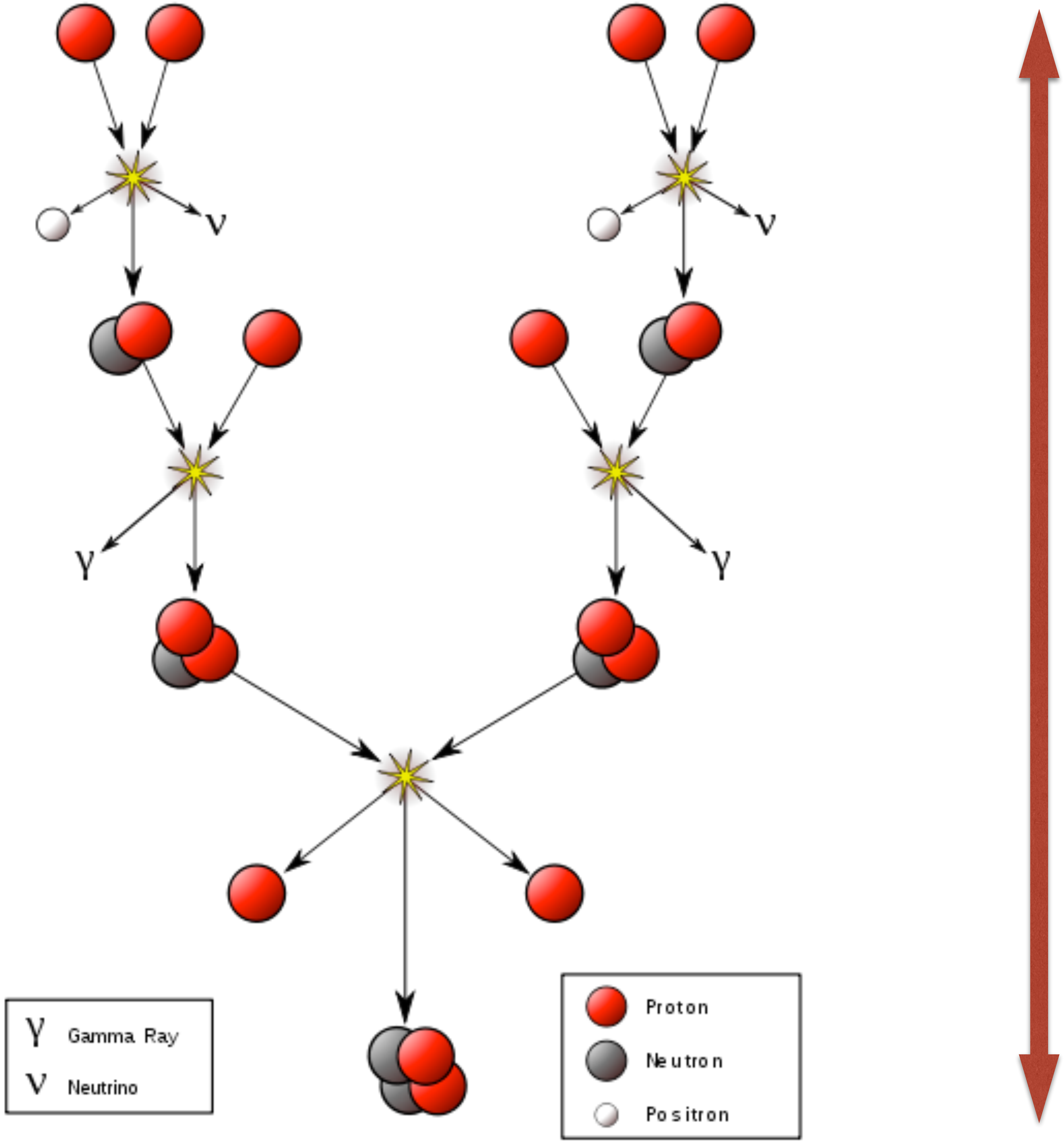


The “pp” chain



28.3 MeV - neutrino

(~ 26.25 MeV)

Q: how many reactions per second should there be?

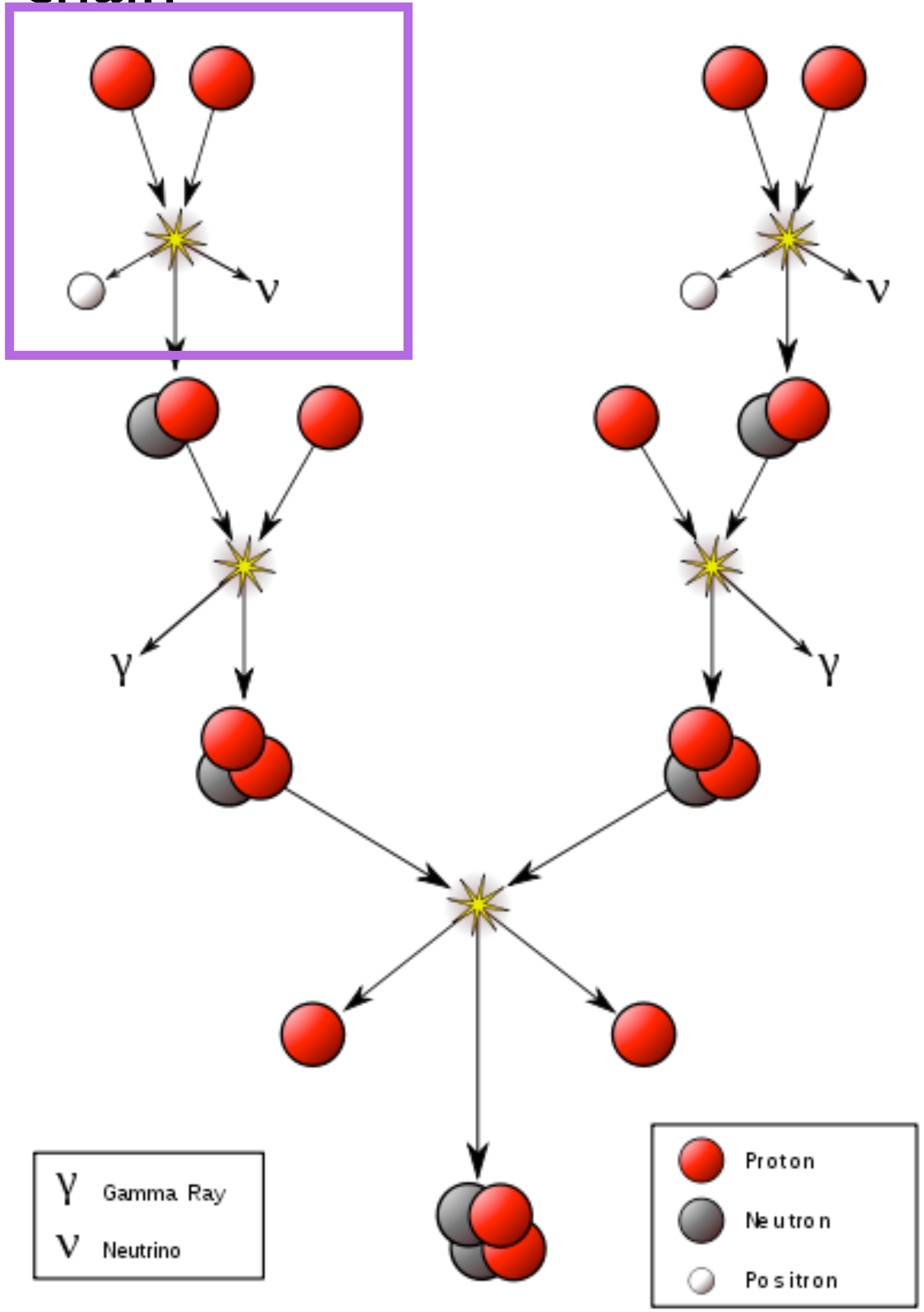
Reaction rate $r = \dfrac{\#\text{ of reaction}}{\text{second volume}}$

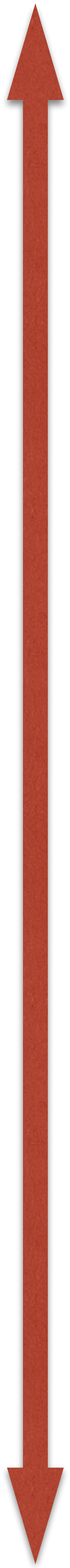
Energy per reaction

$$\epsilon = \frac{\dfrac{\text{Energy}}{\text{second}}}{\text{unit of mass}} = \frac{r \quad Q}{\rho}$$

$\dfrac{\text{mass}}{\text{volume}}$

The "pp" chain





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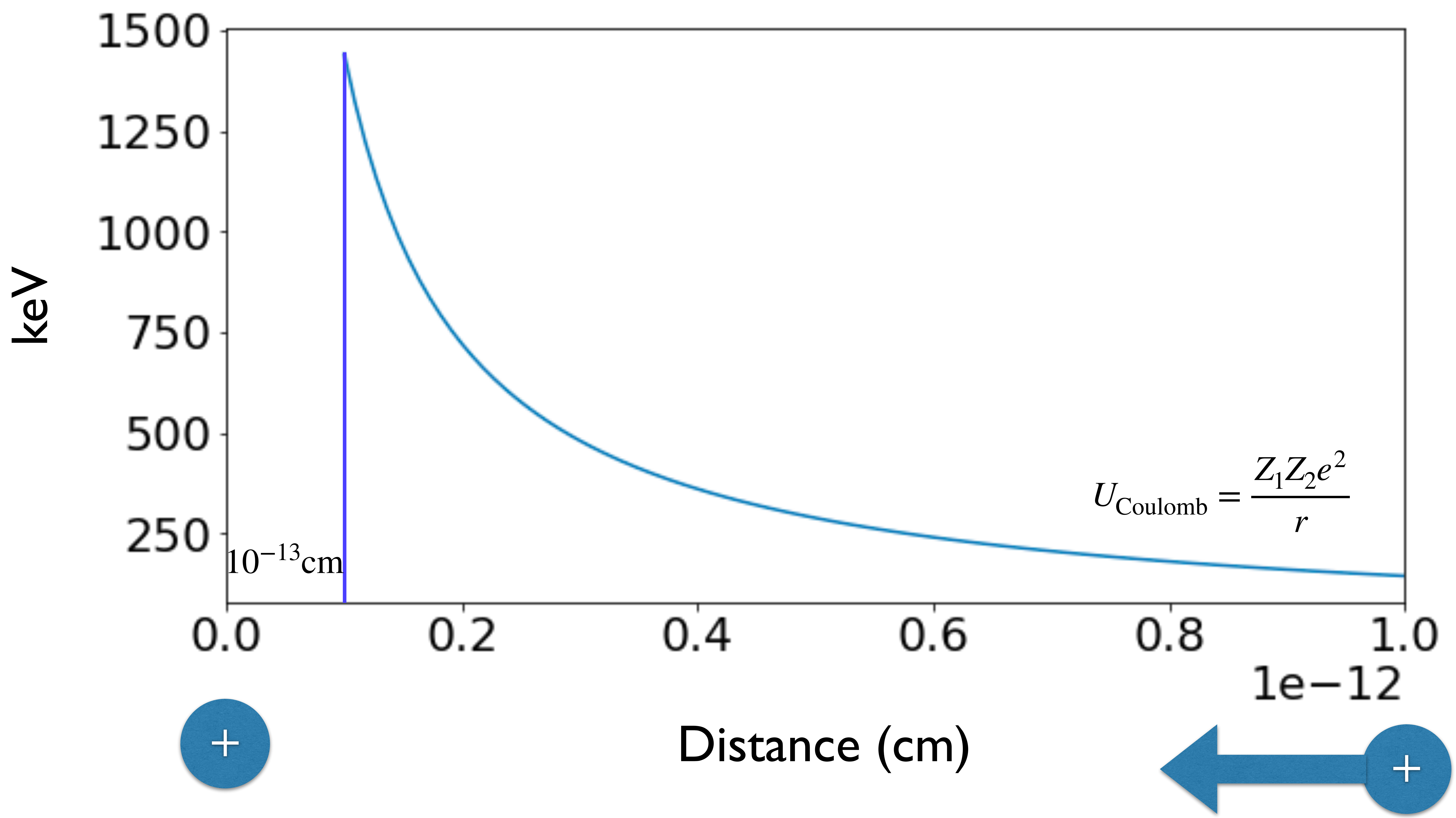

1500
1250
1000
750
500
250
keV
10^{-13}cm
$U_{\text{Coulomb}} = \frac{Z_1 Z_2 e^2}{r}$
0.0
0.2
0.4
0.6
0.8
1.0
1e−12
Distance (cm)
+
+

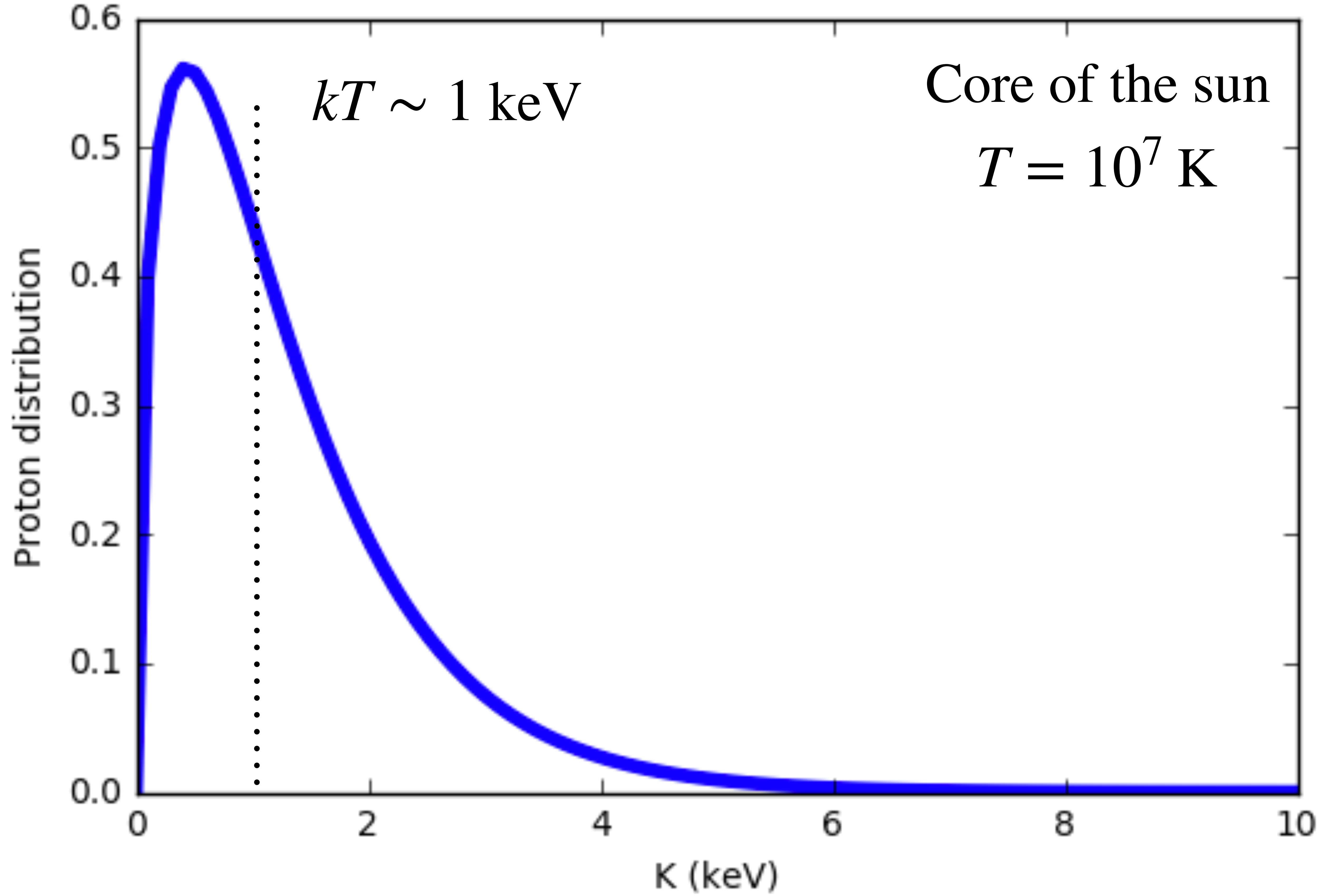
Maxwell-Boltzmann distribution of energy

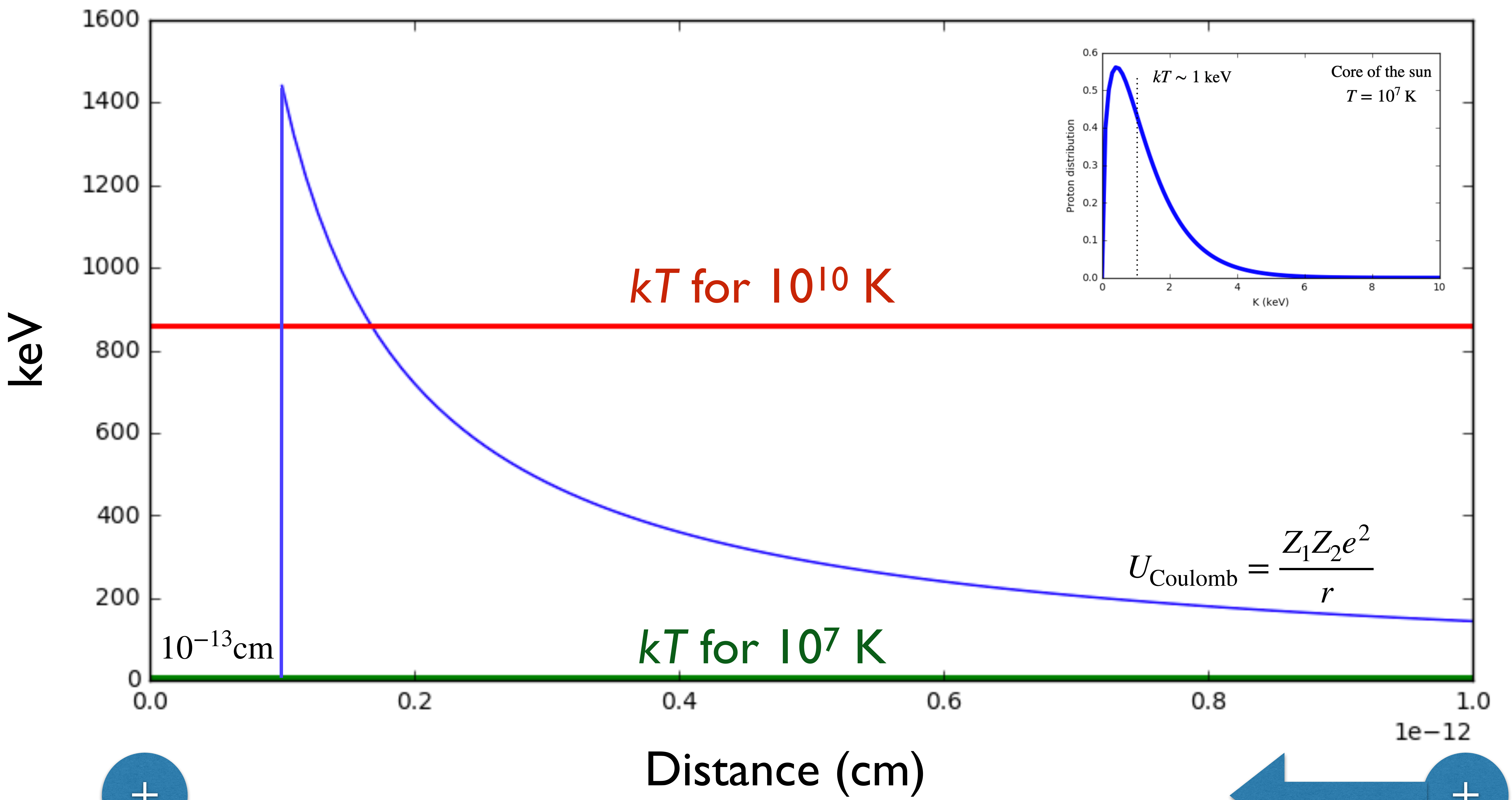
$$f(v) = \left(\frac{m}{2\pi kT}\right)^{3/2} 4\pi v^2 e^{\frac{-mv^2}{2kT}}$$

$$k_B \sim 10^{-7}\ \text{keV / K}$$

$$f(E)dE = f(v)dv$$

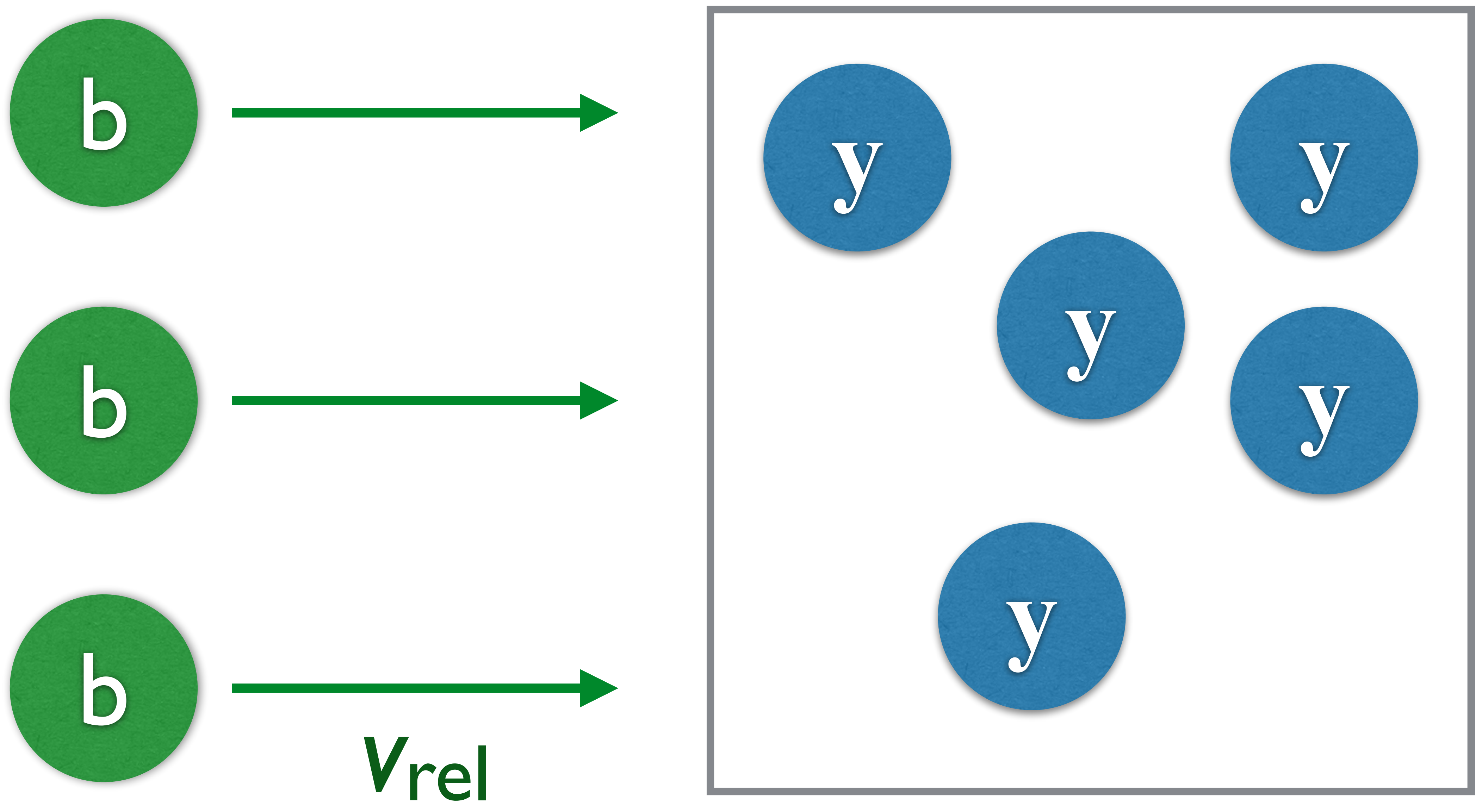
$$f(E) = \left(\frac{E}{\pi}\right)^{1/2} \frac{2}{(kT)^{3/2}} e^{-\frac{E}{kT}}$$





keV
1600
1400
1200
1000
800
600
400
200
0
0.0
0.2
0.4
0.6
0.8
1.0
1e−12
Distance (cm)
kT for 10^{10} K
kT for 10^{7} K
10^{-13}cm
$U_{\text{Coulomb}} = \frac{Z_1 Z_2 e^2}{r}$
Proton distribution
K (keV)
$kT \sim 1$ keV
Core of the sun
$T = 10^7$ K

$$r_{by} = \boxed{\sigma_{by}(v)\ v_{\rm rel}}\ n_b\ n_y$$



Distribution of velocities:
Let's take a weighted mean

$$r_{by} = < \sigma_{by}(v)\ v_{\rm rel} >\ n_b\ n_y$$

$$\epsilon = \frac{< \sigma_{by}(v)\ v_{\rm rel} >\ n_b\ n_y\ Q}{\rho} = \frac{< \sigma_{by}(v)\ v_{\rm rel} >\ \frac{X_b \rho}{A_b m_H}\ \frac{X_y \rho}{A_y m_H}\ Q}{\rho}$$

Intrinsic to collision
(small variation with E, compared to the exponential terms)

$$< \sigma_{by}(v) v_{\rm rel} > = \left(\frac{8}{\pi \mu_{\rm red} (kT)^3} \right)^{1/2} \int_0^\infty S(E) \;\; e^{-E/kT} \;\; e^{-b/E^{1/2}} \;\; dE$$

Tail of the MB distribution

Tunneling prob.

$$b = (8\mu_{\rm red})^{1/2} \;\; \frac{\pi^2 Z_1 Z_2 e^2}{h}$$

Intrinsic to collision
(small variation with E, compared to the exponential terms)

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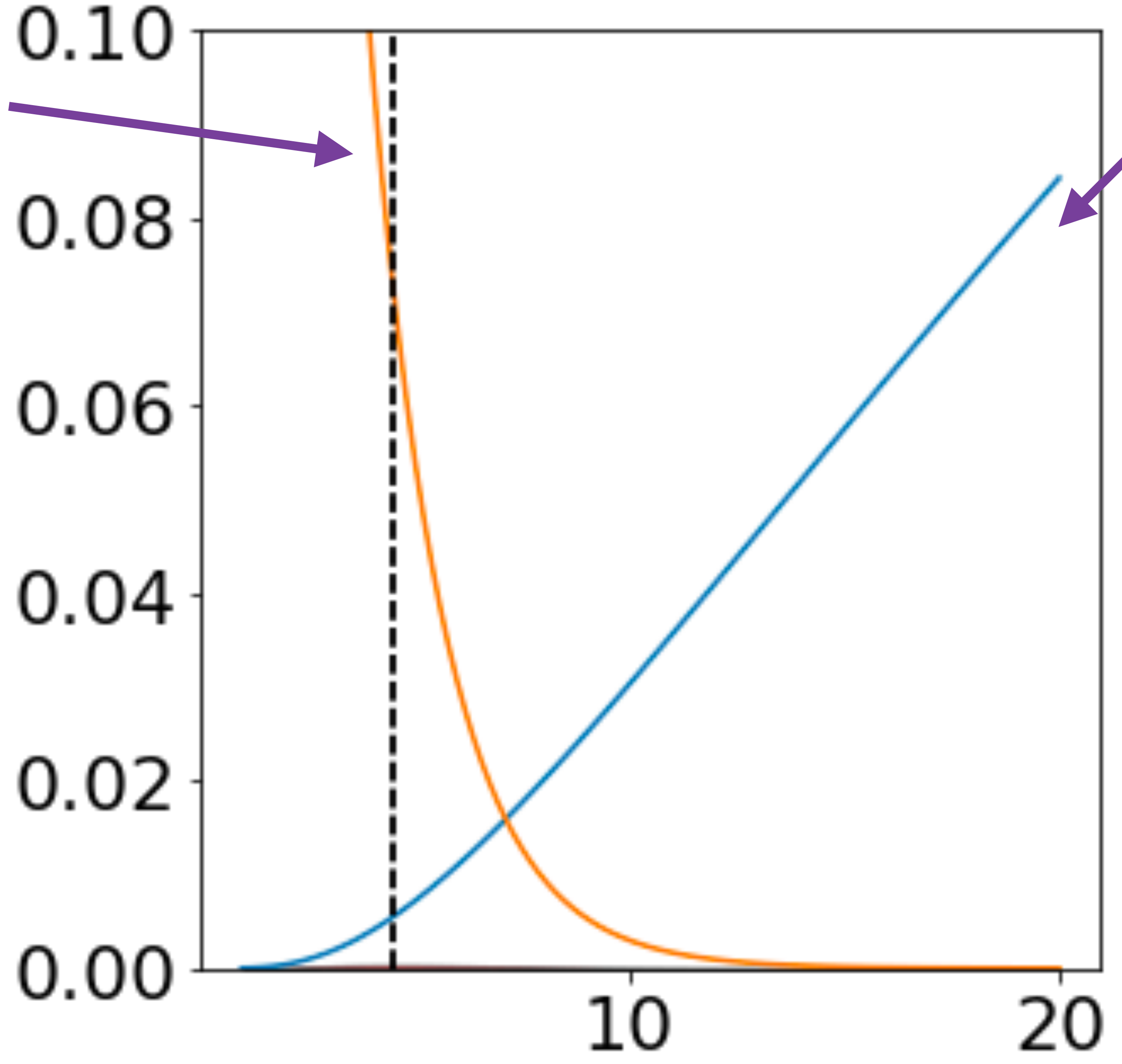

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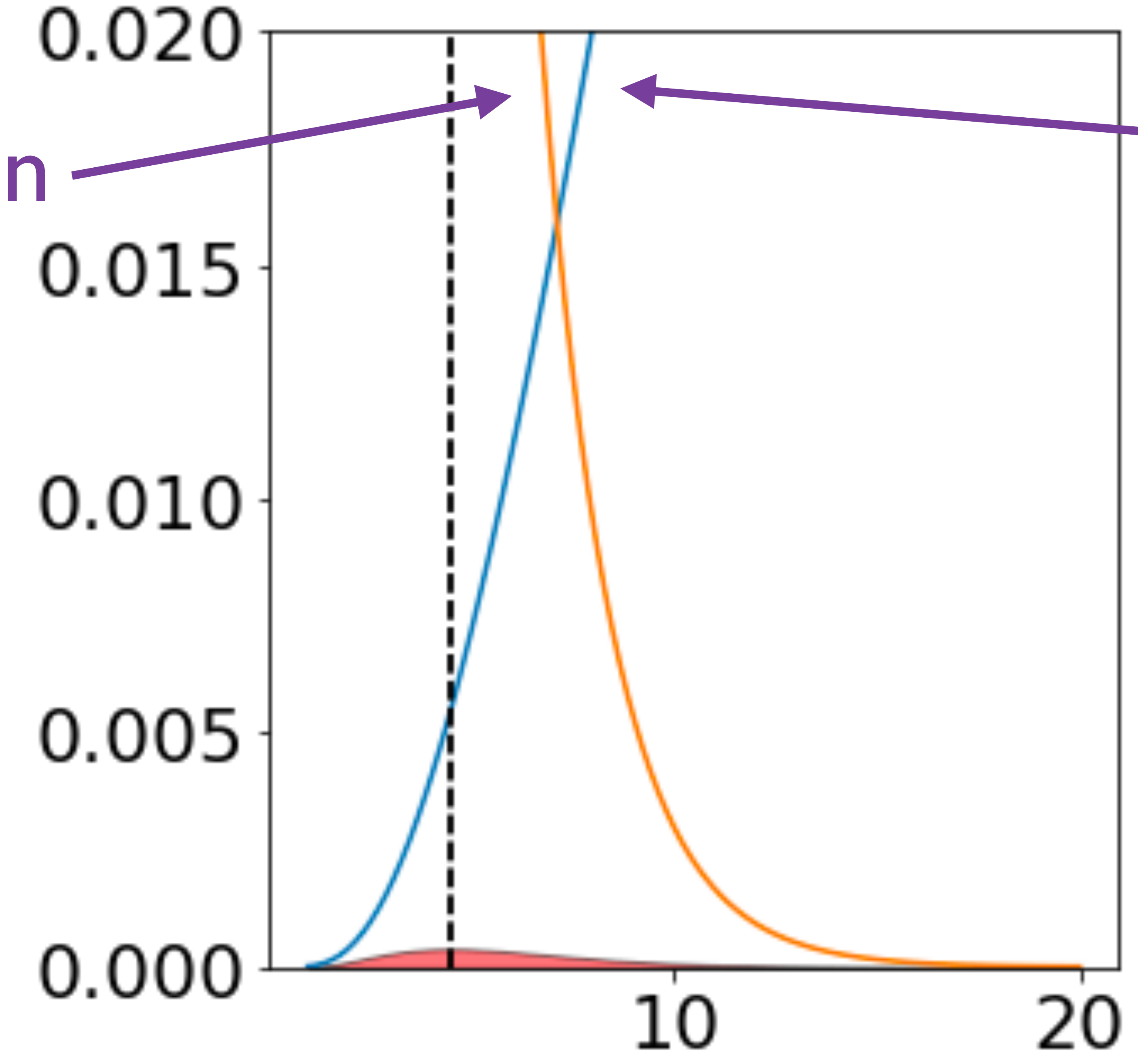

“Gammov peak”